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U.S. ARMY TEST AND EVALUATION COMMAND
TEST OPERATION PROCEDURES

Test Operations Procedure (TOP) 7-3-534

23 December 1994

AIRWORTHINESS TESTING OF FIXED WING AIRCRAFT
(ASYMMETRIC POWER TESTING)

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1. SCOPE. This document establishes procedures and methods for evaluating the asymmetric power handling qualities of multi-engine fixed-wing aircraft during developmental testing. This TOP is limited to handling qualities only and does not address aircraft performance.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities. The actual testing will be performed during flight. An enclosed hangar and appropriate maintenance equipment are required for pretest calibrations and checks.

<u>Item</u>	<u>Requirements</u>
Standard tool sets	Aviation unit maintenance level
Aircraft rigging tools	As specified in technical manuals for aircraft rigging
Aircraft pitot-static test set	As specified in technical manuals for aircraft pitot-static leak checks
Aircraft weighing equipment	As specified in technical manuals for aircraft weight and center of gravity determination

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<u>Item</u>	<u>Requirements</u>
Ballast	Appropriate ballast and securing mechanisms

2.2 Instrumentation.

<u>Devices for Measuring</u>	<u>Measurement of Accuracy</u>	
Preflight fuel weight	2 percent	Accession For
Engine shaft/brake horsepower	2 percent	NTIS CRA&I <input checked="" type="checkbox"/>
Aircraft calibrated airspeed	± 1 knot	DTIC TAB <input type="checkbox"/>
Aircraft pressure altitude	± 20 feet	Unannounced <input type="checkbox"/>
Ambient outside air temperature	± 2 degree C	Justification _____
Flight control positions	1 percent	By _____
Rudder pedal force	± 5 pounds	Distribution / _____
		Availability Codes
		Dist Avail and/or Special
		A-1

3. REQUIRED TEST CONDITIONS.

3.1 Instrumentation. The aircraft instrumentation system (if installed) shall be calibrated and functionally checked.

3.2 Data Required. The following data/information are required prior to the start of testing:

- Aircraft basic weight.
- Aircraft basic center of gravity (cg) location.
- Ballast locations to facilitate the following aircraft loadings:
 - Aft cg, light weight (no cargo, minimum safe fuel load).
 - Aft cg, heavy weight (takeoff at maximum gross weight).
- Calibration equation of the ship fuel system.
- Method to predict aircraft stall speed during flight based on gross weight, density altitude, and configuration (A detailed method to predict aircraft stag speeds is presented in Appendix A).
- Table of propeller efficiencies (obtained from the manufacturer).

- g. Calibrations of installed instrumentation parameters, as appropriate.
- h. Calibration of the aircraft pitot-static system position error.

4. TEST PROCEDURES. The following tests should be performed in presented order.

4.1 Power-Off Stall Characteristics.

a. Method.

- (1) Load aircraft for aft cg and heavy gross weight.
- (2) Aircraft flap/gear as required.
- (3) Perform stalls using the technique outlined in USNTPS-FTM-NO.108¹. Perform three stalls per configuration (only two are required if the recorded stall speeds are equal).

b. Data Required. Record fuel quantity, engine torque/manifold pressure, engine rpm, outside air temperature, stall warning activation, buffet onset, and stall airspeed (V_s) for each test point. Calculate a maximum obtainable lift coefficient ($C_{L_{max}}$) for each aircraft configuration as presented in Appendix A.

4.2 Single-Engine Stall Characteristics.

a. Method.

- (1) Load aircraft for an aft cg and heavy gross weight.
- (2) Aircraft configuration as required.
- (3) Determine the zero-thrust power setting by establishing level (if possible) flight at $1.2 V_s$ (predicted from $C_{L_{max}}$ obtained during power-off stalls) with one engine shutdown and the propeller feathered. While maintaining airspeed, restart the shutdown engine and adjust the engine and propeller controls to maintain the initial trim conditions.
- (4) Set power to 10% maximum allowable on one engine with the other engine set to zero thrust and perform single-engine stalls.
- (5) Increase power on the thrusting engine in 10% increments and repeat the stalls. Testing shall be discontinued if wings-level flight can not be maintained during the entry and recovery or if less than 20% directional control travel remains during the stag entry.

¹Superscript numbers correspond to those Appendix B, References.

b. Data Required. Record fuel quantity, engine torque/manifold pressure, engine rpm, outside air temperature, stall warning activation, buffet onset, and V_s for each test point. Calculate a maximum obtainable C_L for each aircraft configuration. Compare the values of C_L determined during single-engine stalls with those determined during dual-engine stalls for each configuration. Set $C_{L_{max}}$ for each configuration to the lower value for that configuration.

4.3 Static Minimum Control Speed Determination.

a. Method.

- (1) Load aircraft for an aft cg and light gross weight.
- (2) Aircraft landing gear retracted and flaps as required.
- (3) Set one engine's power to 50% maximum allowable with the other engine set to zero thrust and perform static minimum control speed (V_{mc}) tests using the technique outlined in USNTPS-FTM-NO.103². A desired bank angle should be determined and maintained for all test points while maintaining non-turning flight. Testing shall be discontinued at $1.05 V_s$ as calculated from $C_{L_{max}}$ (previously determined).
- (4) Increase power in 10% increments and repeat test.
- (5) Determine critical engine by repeating static V_{mc} tests with zero thrust on the opposite engine.

b. Data Required. Record fuel quantity, engine torque/manifold pressure, engine rpm, outside air temperature, and flight control positions at five knot decrements during each test point. Calculate static V_{mc} as detailed in Appendix A.

4.4 Dynamic Minimum Control Speed Determination.

a. Method.

- (1) Load aircraft for an aft cg and light gross weight.
- (2) Trim aircraft to 20 knots above the higher of the aircraft operator's manual minimum allowable operating airspeed or static V_{mc} (previously determined) and perform dynamic V_{mc} tests using the technique outlined in USNTPS-FTM-NO.103.
- (3) Decrease airspeed in 5 knot increments (2 knot increments are used to determine the final value) and repeat test. Testing shall be discontinued at $1.05 V_s$ as calculated from $C_{L_{max}}$ (previously determined).

b. Data Required. Record fuel quantity, engine torque/manifold pressure, engine rpm, outside air temperature, and flight control positions during each test point.

5. PRESENTATION OF DATA.

a. Test condition data from all tests will be included in the general overall test condition table generated for the final test report. Data should be analyzed using the method detailed in Appendix A and presented in the final test report.

b. Results from the power-off and single-engine stall characteristic testing should be summarized in a table similar to the example shown below:

Table X. Stall Characteristics Summary¹

Flap Position (deg)	Left Engine Torque (%)	Right Engine Torque (%)	Stall Warning Airspeed (KCAS ²)	Buffet Airspeed (KCAS)	Stall Airspeed (KCAS)	Maximum Lift Coefficient
0	0	0	110	105	100	1.7
4	0	0	99	95	90	1.8
15	0	0	93	90	85	2.1
35	0	0	77	75	70	2.5
0	0	60	109	103	100	1.7
4	0	60	101	93	90	1.8
15	0	60	94	89	85	2.1
35	0	60	76	76	70	2.5
0	60	0	110	104	100	1.7
35	60	0	77	72	70	2.5

NOTES:

¹Test conducted at 19,000 lb gross weight with an average cg located at fuselage station 250.0 (AFT)

²KCAS: knots calibrated airspeed

c. Results from the static and dynamic V_{mc} determination testing should be presented in tabular form similar to the following examples:

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Table X. Minimum Control Airspeed

Flap Position (deg)	Gear Position	Config A V_{mc} (KCAS ¹)	Config B V_{cm} (KCAS)	Change ² in V_{cm} (KCAS)	Operator's Manual V_{mc} (KCAS)	Calculated Stall Speed ³ (KCAS)
35	Down	78	81	3	79	62
15	Down	72	73	1	77	68
4	Down	63	65	2	77	74
0	Up	63	65	2	80	76

NOTES:

¹KCAS: knots calibrated airspeed

²Change in V_{mc} from Configuration A to Configuration B

³Stall speed based on power-off maximum lift coefficient and a representative minimum flying weight of 16,500 lb.

APPENDIX A. BACKGROUND

AIRWORTHINESS TESTING OF FIXED WING AIRCRAFT (ASYMMETRIC POWER TESTING)

1. TESTING CONSIDERATIONS.

1.1 Test Aerodynamics. During flight with asymmetric power, the minimum control airspeed (V_{mc}) will be defined by either control authority limits or aircraft stall. As the aircraft is decelerated in non-turning flight with asymmetric power applied, the amount of rudder and aileron control required increases. Depending on the specific characteristics of the test aircraft, the aircraft will depart controlled flight at the airspeed where control stops are contacted or at the stall airspeed. Test conditions should be devised to avoid having these two airspeeds coincide. The stall speed can be manipulated by varying aircraft gross weight. By performing stalls at heavy gross weights and V_{mc} testing at light gross weights the difference in these speeds are maximized. At no time should the aircraft be allowed to stall with the flight controls positioned near the control stops (less than 20% remaining) due to the likelihood of entering an inadvertent spin. A detailed discussion of asymmetric powered flight aerodynamics is contained in reference 1.

1.2 Procurement/Certification Requirements.

a. Procurement/Certification Documents. U.S. Army fixed-wing aircraft are usually procured using Military Specification MIL-F-8785C, Flying Qualities of Piloted Airplanes³ as a guide or they are procured after the aircraft are certified according to Federal Aviation Regulations (FAR)⁴. Most powered fixed-wing aircraft are certified to either FAR Part 23, Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes or FAR Part 25, Airworthiness Standards: Transport Category Airplanes. The Federal Aviation Administration also publishes Advisory Circular (AC) 23-8A, Flight Test Guide for Certification of Part 23 Airplanes⁵ and AC 25-7, Flight Test Guide for Certification of Transport Category Airplanes⁶.

b. Asymmetric Power Stall Characteristics.

(1) Military Specification MIL-F-8785C paragraph 3.4.2.1.3.1 requires that the aircraft must be safely recovered from single-engine stalls with up to maximum power applied to the operating engine(s). This paragraph applies to the takeoff, climb, power approach, and wave-off flight phases.

(2) FAR Part 23 and Part 25 require that one-engine-inoperative stalls be demonstrated at up to the lesser of 75% maximum continuous power or the power or thrust at which no lateral control margin remains during the approach to the stall. Both parts only require that stalls be demonstrated in the flaps up, gear up configuration. As of January 1993, aircraft certified to Part 25 standards do not need to demonstrate acceptable asymmetric power stall characteristics. The rationale for this decision was that Part 25

operating requirements (operating airspeeds and performance requirements) minimize the possibility of an aircraft entering an asymmetric power stall.

c. Minimum Control Speed Characteristics.

(1) Military Specification MIL-F-8785C paragraph 3.3.9.2 requires that during takeoff, it is possible to maintain straight flight following sudden asymmetric loss of thrust at the minimum takeoff speed. Straight flight must be maintained throughout the climbout without changing configuration. Control forces may not exceed 180 lb for yaw and 70 lb (35 lb if equipped with a control stick) for roll. Roll control margin must be greater than 25% with the trim set for takeoff. Automatic devices which normally operate in the event of a thrust failure may be used. The airplane may be banked up to five degrees away from the inoperative engine.

(2) FAR Part 23 and 25 require that V_{mc} be determined with the aircraft loaded and configured as follows:

(a) Critical weight and center of gravity. This is normally a light gross weight (minimizing the benefit of banking into the operating engine) and an aft cg (providing the shortest rudder restoring moment arm). The FAR specifies the maximum sea level takeoff weight (or any lesser weight necessary to show V_{mc}).

(b) Rudder and aileron controls adjusted to minimum allowable travel and cable tension.

(c) Maximum allowable fuel imbalance.

(d) Flaps set to the takeoff setting. Tests must be repeated for each approved takeoff flap setting.

(e) Trim set for normal takeoff.

(f) Landing gear retracted. The extended landing gear are usually a stabilizing influence.

(g) Critical engine inoperative with the propeller windmilling or feathered if the aircraft is equipped with an automatic feathering device. Testing must be accomplished to determine which engine is critical. Takeoff power set on the remaining engine(s).

(h) Up to five degrees of bank away from the inoperative engine may be used. Pedal forces may not exceed 150 lb. The data is analyzed and extrapolated to sea level standard conditions. Dynamic V_{mc} tests are performed in the same configuration and results are compared to those obtained during static V_{mc} tests. The highest value of static V_{mc} , dynamic V_{mc} , and stall speed is V_{mc} .

2. DATA ANALYSIS.

2.1 Stall Speed Prediction. A maximum lift coefficient ($C_{L_{max}}$) for each flap setting can be calculated as follows:

$$C_{L_{max}} = L/q_s S \quad (1)$$

Where:

L = lift = aircraft gross weight times load factor (lb),
S = wing area (ft²),
 q_s = dynamic air pressure at stall (lb/ft²) = $1/2 Q_o V_s^2$,
 Q_o = standard day, sea level air density = .002376892 (slug/ft³)
 V_s = calibrated stall airspeed (ft/sec)

Stall speeds can be predicted using these maximum lift coefficients as follows:

$$V_s = \sqrt{\frac{2L}{Q_o C_{L_{max}} S}} \quad (2)$$

2.2 Minimum Control Speed Data Analysis. During asymmetric powered flight, the yaw moment resulting from asymmetric thrust must be countered to maintain zero turn rate flight. A free-body diagram can be developed as shown in figure A-1.

Where:

T = Thrust (lb)
 1T = Representative lateral distance from the aircraft cg to the thrust axis (ft)
 N_B = Yaw moment due to sideslip (ft-lb)
 β = Angle of sideslip (deg)
 Y_B = Sideforce due to sideslip (lb)
 L_F = Vertical-tail lift force (lb)
 1F = Representative longitudinal distance from the aircraft center of gravity to the longitudinal center of vertical tail lift (ft)
 $W \sin \phi$ = Lateral component of weight due to bank angle (lb)
 ϕ = Angle of bank (deg)

For the aircraft to be in equilibrium, the sum of the forces and moments acting on the aircraft must be zero.

$$\Sigma F_Y = 0 \quad (3)$$

$$W \sin \phi = Y_B - L_F = 0 \quad (4)$$

$$\Sigma N_{\text{center of gravity}} = 0 \quad (5)$$

$$-T^1T + N_B + L_F^1F = 0 \quad (6)$$

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Assuming β is small:

$$Y_\beta = 0 \quad (7)$$

$$W \sin \phi = L_F \quad (8)$$

$$N_\beta = 0 \quad (9)$$

and:

$$L_F l_F = T l_T = \frac{550 \text{ THP}}{V_T} l_T \quad (10)$$

Where:

$$T = 550 \text{ THP}/V_T \quad (11)$$

$$\text{THP} = \text{Thrust horsepower } n_p \text{ SHP or } n_p \text{ BHP} \quad (12)$$

$$\text{SHP} = \text{Shaft horsepower} = Q_E N_p 2\pi / 33,000 \quad (13)$$

$$n_p = \text{Propeller efficiency}$$

$$\text{BHP} = \text{Brake horsepower (reciprocating engines)}$$

$$V_T = \text{True airspeed (ft/sec)}$$

$$Q_E = \text{engine torque (ft-lb)}$$

$$N_p = \text{propeller speed (rpm)}$$

Equation 10 can be nondimensionalized into a yaw moment coefficient as follows:

$$C_N = \frac{L_F l_F}{1/2 \rho V_T^2 S b} = \frac{\frac{550 \text{ THP}}{V_T} l_T}{1/2 \rho V_T^2 S b} \quad (14)$$

Simplifying:

$$C_N = \frac{550 \text{ THP} l_T}{1/2 \rho V_T^3 S b} \quad (15)$$

Where:

$$C_N = \text{Yaw moment coefficient}$$

$$b = \text{Wing span (ft)}$$

At the low airspeeds and altitudes used during V_{mc} testing, the following approximation is quite accurate:

$$V_T = \frac{V_c}{\sqrt{\sigma}} \quad (16)$$

Where:

V_C = Calibrated airspeed (ft/sec)
 σ = Ambient atmospheric density ratio (Q/Q_o)

Substituting equation 16 into equation 15 yields:

$$C_N = \frac{550 \text{ THP } l_T}{1/2 Q \frac{V_C^3}{\sigma \sqrt{\sigma}} S b} \quad (17)$$

Simplifying:

$$C_N = \frac{550 \text{ THP } l_T \sqrt{\sigma}}{1/2 Q_o V_C^3 S b} \quad (18)$$

Substituting equation 12 into equation 18 yields:

$$C_N = \frac{550 \eta_p \text{ SHP } l_T \sqrt{\sigma}}{1/2 Q_o V_C^3 S b} \quad (19)$$

2.3 Yaw moment coefficient is plotted versus rudder position (or pedal force) for each aircraft configuration. The data (presented in fig A-2) is extrapolated to determine the maximum obtainable yaw moment coefficient obtainable for each aircraft configuration using maximum available rudder (or limit control force) (assuming no stall). Equation 18 is solved for the minimum airspeed (ft/sec) at which the rudder can generate the maximum value of C_N for a given altitude and THP as follows:

$$V_C = 3 \sqrt{\frac{550 \text{ THP } l_T \sqrt{\sigma}}{1/2 Q_o C_{N_{\max}} S b}} \quad (20)$$

Where:

$C_{N_{\max}}$ = Maximum yaw moment coefficient obtainable for a specific aircraft configuration

Equation 20 is used to generate a curve of calibrated airspeed versus THP at the maximum value of C_N for sea level, standard day atmospheric conditions, for each aircraft configuration (fig A-3). THP is a function of η_p as illustrated in equation 12. η_p , and therefore THP, is a function of airspeed for a given engine power. Using maximum allowable engine shaft power for sea level, standard day atmospheric conditions, a curve of THP versus calibrated airspeed is calculated using equation 12, and plotted on figure A-3. The point of intersection of the lines of constant SHP and constant C_N represent the minimum airspeed at which maximum rudder deflection will generate just enough yaw moment to counter the moment generated by maximum power on a

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single engine at sea level standard day conditions. If this speed is higher than the single-engine stall speed, then it is V_{mc} , if not, then V_{mc} is the single-engine stall speed.

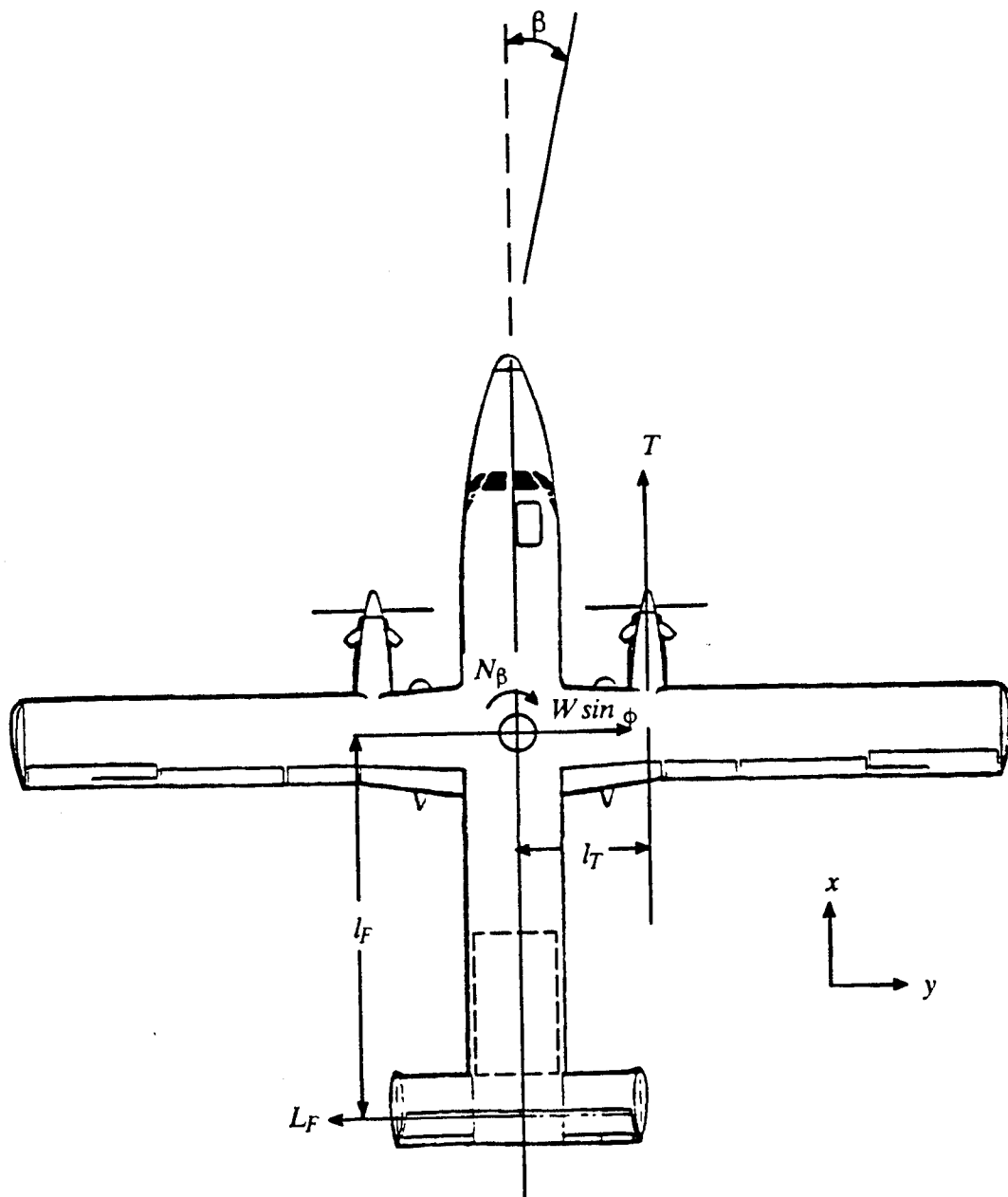


Figure A-1. Free-Body Diagram (Assume Aircraft is in a Right Bank)

SYMBOL	AVG GROSS WEIGHT (LB)	AVG LONGITUDINAL CG LOCATION (FS)	AVG DENSITY ALTITUDE (FT)	AVG OAT (DEG C)	FLAP SETTING (DEG)	LANDING GEAR POSITION
△	18,330	237.8	6410	9.5	35	DOWN
○	18,490	238.2	6970	10.0	15	DOWN
□	18,630	238.5	6990	10.5	4	DOWN
◇	18,140	237.3	6810	9.5	0	UP

- NOTES:
1. CONFIGURATION A (BASELINE)
 2. LEFT ENGINE OPERATING AT IDLE POWER
 3. RIGHT ENGINE OPERATING AT INCREMENTAL POWERS UP TO MAXIMUM AVAILABLE (1040 SHP)
 4. BOTH PROPELLERS SET FOR 1675 RPM
 5. ONE FAIRING OBTAINED FOR BOTH 0 AND 4 DEGREE FLAP SETTINGS
 6. TESTING TERMINATED FIVE KNOTS ABOVE THE PREDICTED STALL SPEED
 7. DASHED LINES REPRESENT EXTRAPOLATED DATA

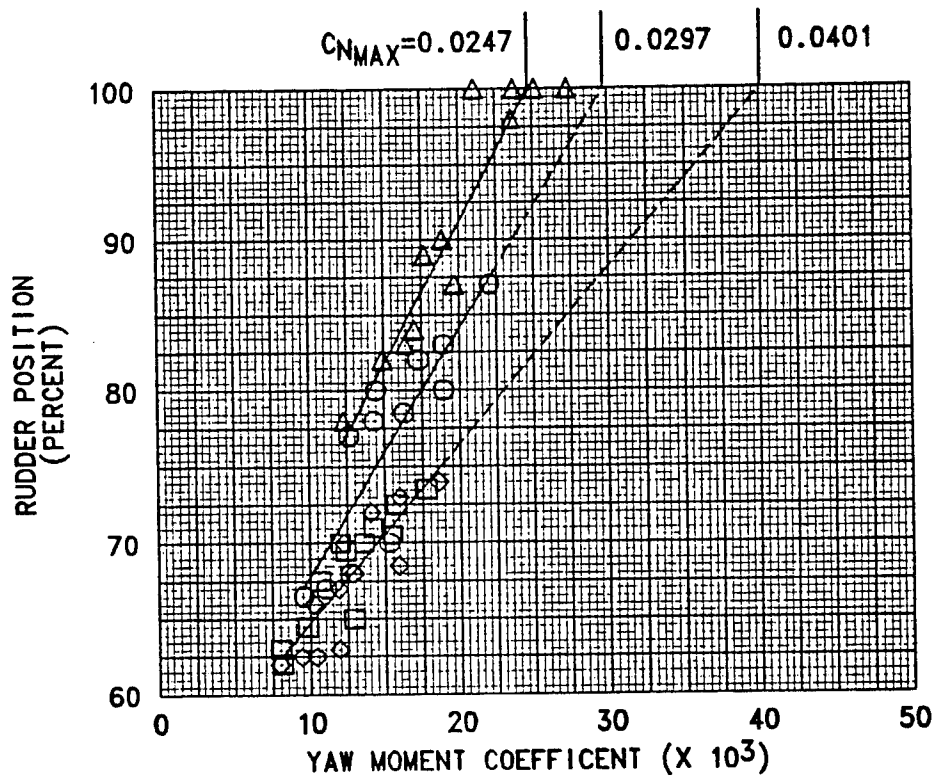


Figure A-2. Maximum Yaw Moment Coefficient Determination

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- NOTES:
1. 35 DEGREE FLAP SETTING, LANDING GEAR DOWN
 2. SEA LEVEL STANDARD DAY CONDITIONS
 3. DASHED LINE REPRESENTS THRUST HORSEPOWER AVAILABLE BASED ON 1180 ENGINE SHAFT HORSEPOWER AND PROPELLER EFFICIENCY
 4. SOLID LINES BASED ON MAXIMUM YAW MOMENT COEFFICIENT (C_{NMAX}) AT FULL RUDDER DEFLECTION FROM FIGURES A-2
 5. V_{mc} IS DEFINED BY THE INTERSECTION OF THE LINES

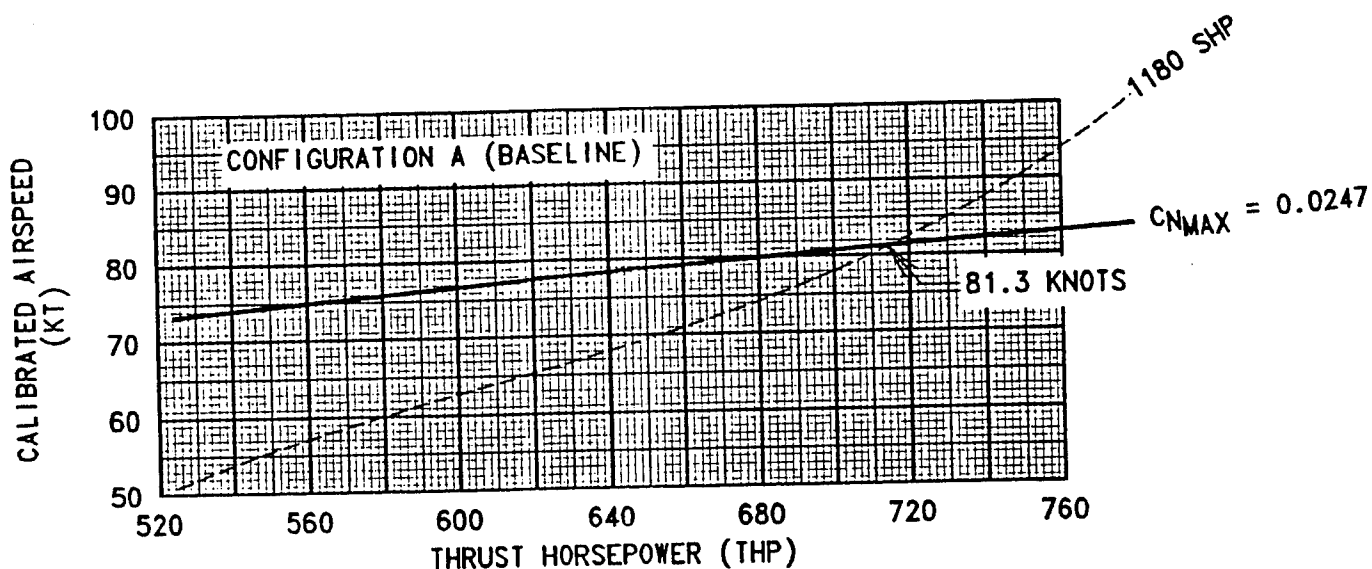
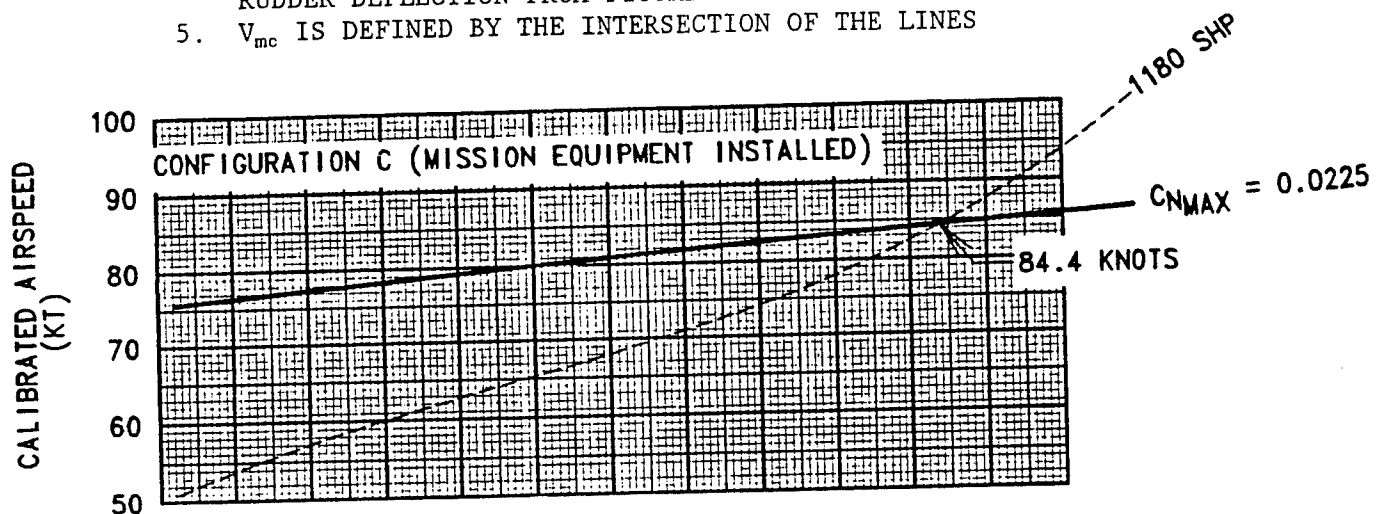


Figure A-3. V_{mc} Determination

APPENDIX B. REFERENCES

1. Flight Test Manual, Naval Air Test Center, FTM 108 (Preliminary), Fixed Wing Performance, 30 September 1992.
2. Flight Test Manual, Naval Air Test Center, FTM 103, Fixed Wing Stability and Control, 1 November 1981.
3. Military Specification, MIL-F-8785C, Flying Qualities of Piloted Airplanes, 5 November 1980.
4. Code of Federal Regulations, Title 14, Aeronautics and Space, 1 January 1993.
5. Advisory Circular, Federal Aviation Administration, AC 23-8A, Flight Test Guide for Certification of Part 23 Airplanes, 8 February 1989, w/change 1, 30 August 1993.
6. Advisory Circular, Federal Aviation Administration, AC 25-7, Flight Test Guide for Certification of Transport Category Airplanes, 9 April 1986.

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